RESEARCH REPORT FOR SCHOOL OF THEORETICAL PHYSICS, 2012

June 24, 2013

1 REPORT ON RESEARCH WORK

1.1 Work by Senior Professors and Collaborators

1.1.1 Riemann Surfaces

(W. Nahm with M. Leitner)

Together with M. Leitner, we investigated rational conformally invariant quantum field theories on Riemann surfaces of higher genus. For genus 1 the partition functions of such theories are modular. For higher genus the partition functions will yield generalisations, but apart from the case of free fermions very little is known about them. So far we have developed techniques which reproduce the genus 1 results in an algebraically convenient way and have a very good chance to work equally well in higher genus. The first case to be solved is the (2,5) minimal model on hyperelliptic Riemann surfaces, for which a publication is expected in 2013.

1.1.2 Ising Correlators

(W. Nahm with T. Spencer)

A visit of T. Spencer from the Princeton Institute of Advanced Studies led to research on Ising correlators with an unexpected link to previous work of Nahm's on modular forms and hypergeometric series. It turned out that the two-point correlators of the Ising model at the phase transition can be expressed in terms of polynomials with integer coefficients evaluated on the well known values on the diagonal. This result was presented at a conference in Bad Honnef, but has not yet been written up.

1.1.3 Vanishing Theorems

(W. Nahm with F. Laytimi)

Research with F. Laytimi (Lille Univ.) on vanishing theorems was continued during a visit to Lille. A paper with the title "A general vanishing theorem "was accepted in November 2012 and will appear in volume 123 of the *Proceedings of Mathematical Sciences*. A further paper with the title "Generation by Sections and k-Ampleness "was submitted to the *Journal of Algebra*.

1.1.4 Assyriology

(W. Nahm)

My Assyriological research arose from the School of Celtic Studies project of a 3D recording of all Ogham stelae. This project was initiated together with the School of Theoretical Physics. In order to facilitate a collaboration with German partners I looked at more than

100 stelae found at Assur in a German excavation early in the 20th century. I demonstrated that scientific methods can extract important new historical information from these stelae and suggested a 3D recording. The paper with the title "The Placement and Chronological Sequence of the Stelae from Assur "appeared in *Altorientalische Forschungen*, volume 39, issue 1, pp. 112-123, in December.

I also started work on the Assyrian and Babylonian chronology of the 2nd millenium BC. In this millennium there were two major crises, possibly due to climate change. Their study may have important consequences for the understanding of plagues and agricultural reorganisation due to the climate. Comparison between historical developments and environmental changes needs a reliable chronology, but currently used chronologies differ by up to 152 years. The solution of this problem depends on a reanalysis of Old Babylonian Venus observations and the date of a solar eclipse. Moreover a major volcanic event in 1628/1627 BC, which also led to reduced growth in oaks recovered from Irish bogs, can be correlated with a reduced visibility of Venus in 1627 and 1626 BC. A publication in *Altorientalische Forschungen* is expected in 2013.

1.1.5 Definition of the Feynman Path Integral

(T.C. Dorlas & M. Beau)

Together with Dr. Mathieu Beau, work was started on a new mathematical approach to the Feynman path integral, defining it as a so-called 'path distribution' on a Hilbert space of paths. This approach was initiated by the late Prof. Erik Thomas (Groningen). He proposed to first consider discrete-time paths (sequences). He formulated the Feynman 'integral' as a path distribution on nuclear sequence spaces. We replaced the nuclear spaces by more easily manageable Sobolev spaces and used the Sazonov theorem to prove the existence of a measure (the Feynman-Thomas measure) on a Sobolev space of paths with discrete time, i.e. sequences. The Feynman 'integral' is then a (path-)derivative of this measure. This formulation allows the 'integration' of potentials which are twice differentiable functions. Moreover, we also extended this formulation to different boundary conditions, enabling us to express the wave operators and thereby also the scattering operator as a Feynman path integral. This work will be published in volume 24 of *Indagationes Mathematicae* in 2013 and was communicated at a conference in Tallinn. Work is now in progress to extend this work to continuous-time paths.

1.1.6 Scattering Completeness for the Toda Lattice

(T.C. Dorlas & I. Lyberg)

In collaboration with Dr. Ivar Lyberg, a direct approach is being explored for the proof of the completeness of scattering (generalised) eigenfunctions of the Toda lattice. The eigenfunctions have been found by Lebedev and Kharchev using the algebraic Bethe Ansatz approach. They are expressed as Mellin-Barnes-type formulas which generalise those for the modified Bessel functions. They are related to the Whittaker functions which are known to be complete as they are related to representations of $GL(n, R)$. Completeness for such representations was proved by Harish-Chandra, but the proof is very complicated. It is therefore desirable to have a direct proof. So far, we have been able to treat only the 2-particle case, but it looks likely that our approach can be extended to the n-particle case. This approach should also give rise to a new series expansion for the eigenfunctions. Work is in progress.

1.1.7 Lectures on Large Deviations

(T.C. Dorlas)

A series of lectures on Large Deviation Theory is being written up for publication. It is hoped that this can be completed before the summer of 2013.

1.1.8 Properties of Subentropy

(T.C. Dorlas & N. Datta)

The concept of subentropy was introduced by Jozsa, Robb and Wootters as a lower bound for the accessible information. Together with Nilanjana Datta (Cambridge) we explored various properties of this quantity, in particular the operator concavity and continuity. We also proved that it is a lower bound for the min-entropy and introduced a concept of conditional subentropy and conjecture that this is a lower bound for the conditional min-entropy for classical-quantum states. We could only prove this in a few special cases however. This work is currently being written up.

1.1.9 Update on Research Team

(D. O'Connor)

All of the current temporary members of Denjoe O'Connor's research team are due to finish their contracts in 2013.

Unfortunately, the outlook for replacing them looks bleak.

External funding for basic research in theoretical physics has disappeared. This happened with the abolition of residual funding for basic research by SFI and then with the disappearance of IRCSET in a merger with IRCHSS to form the IRC. The latter merger cut funding for postdoctoral and postgraduate fellowships.

In this atmosphere DIAS also has suffered serious cutbacks. Postdoctoral positions in STP have not been advertised for several years and a once flourishing visitor program has been eliminated.

The overall result has meant that the number of applications for postdoctoral positions has fallen from the hundreds to a handful.

In this atmosphere it is difficult to be optimistic about the prospects for replacing the current research team. However, should things turn around in 2013 or even 2014 there is still a chance of saving what was gained in the preceding decade.

1.1.10 Scalar and Spinor Field Actions on Fuzzy S^4

(D. O'Connor with J. Medina, I. Huet, B. P. Dolan)

We present a manifestly Spin(5) invariant construction of squashed fuzzy CP^3 as a fuzzy S^2 bundle over fuzzy S^4. We develop the necessary projectors and exhibit the squashing in terms of the radii of the S^2 and S^4. Our analysis allows us to give both scalar and spinor fuzzy action functionals whose low lying modes are truncated versions of those of a commutative S^4.

1.1.11 Matrix Geometries and Matrix Models

(D. O'Connor with R. Delgadillo-Blando)

We study a two parameter single trace 3-matrix model with SO(3) global symmetry. The model has two phases, a fuzzy sphere phase and a matrix phase. Configurations in the matrix phase are consistent with fluctuations around a background of commuting matrices whose eigenvalues are confined to the interior of a ball of radius R=2.0. We study the co-existence curve of the model and find evidence that it has two distinct portions one with a discontinuous internal energy yet critical fluctuations of the specific heat but only on the low temperature side of the transition and the other portion has a continuous internal energy with a discontinuous specific heat of finite jump. We study in detail the eigenvalue distributions of different observables.

1.1.12 Near Commuting Multi-Matrix Models

(D. O'Connor with V. G. Filev)

We investigate the radial extent of the eigenvalue distribution for Yang-Mills type matrix models. We show that a three matrix Gaussian model with complex Myers coupling to leading order in strong coupling is described by commuting matrices whose joint eigenvalue distribution is uniform and confined to a ball of radius $R = (\frac{3\pi}{2g})^{(1/3)}$. We then study, perturbatively, a 3-component model with a pure commutator action and find a radial extent broadly consistent with numerical simulations.

1.2 Independent Work by Schrödinger Fellows

1.2.1 String Theory Compactifications

(V. Braun)

My research is in the general area of string theory, and in particular on the geometry and topology of string theory compactifications. In particular, I continued my ongoing research on F-theory compactifications down to 4 and 6 space-time dimensions. One fundamental question that has not been satisfactorily understood is the role of sections in the corresponding elliptic fibrations. In collaboration with Thomas W. Grimm and Jan Keitel, I analyzed a much more complicated example of an elliptically fibered Calabi-Yau manifold with Mordell-Weil rank one, which led to some unexpected U(1)-charges on matter fields. This is important for particle physics phenomenology as the unbroken global U(1) symmetry can be used to constrain proton decay in GUT models.

1.2.2 Gauge Theories

(S. Kovacs)

The focus of Dr. Kovacs' research is on the study of the interconnections between gravity and gauge theories. He has worked on various aspects of supersymmetric gauge theories and their relations to string and M-theory in the context of the so-called AdS/CFT correspondence.

1.2.3 Gauge-Invariant Correlation Functions for $\mathcal{N} = 4$ SYM in Light-Cone Superspace

(S. Kovacs with S. Ananth and S. Parikh)

The $\mathcal{N} = 4$ supersymmetric Yang–Mills (SYM) theory has been a major focus of investigation in the past few years because of its many remarkable properties. It possesses maximal (rigid) supersymmetry and it is a prime example of an interacting conformally invariant theory in four dimensions. This theory plays a central role in the AdS/CFT correspondence. The latter is a 'holographic' duality relating string theory in certain manifolds to ordinary gauge theories defined on the boundary of such manifolds. The most studied and best understood example of this duality relates $\mathcal{N} = 4$ SYM to the so-called type IIB superstring theory in a background, $\mathrm{AdS}_5 \times S^5$, consisting of the direct product of a five-dimensional anti de-Sitter space and a five-sphere. A central role in this duality is played by gauge-invariant correlation functions. These are the fundamental observables in $\mathcal{N} = 4$ SYM, as in any conformal field theory, and the AdS/CFT correspondence relates them to certain scattering amplitudes in string theory.

Dr. Kovacs, in collaboration with Dr. Sudarshan Ananth and Sarthak Parikh (of the Indian Institute of Science Education and Research, Pune, India) has developed a formalism for the study of gauge-invariant operators in $\mathcal{N} = 4$ SYM using the light-cone superspace formulation. This approach has the unique feature of manifestly preserving the full $\mathcal{N} = 4$ supersymmetry of the theory. The current work concerns a class of four-point correlation functions of operators in the energy-momentum tensor multiplet, computed in configuration space. The results agree with those obtained using other methods. The formalism developed in this project has great potential thanks to the manifest supersymmetry. It is expected to prove very efficient for higher order calculations and work is on-going on generalisations of the current results.

The study of correlation functions of gauge-invariant operators has also allowed to rule out potential drawbacks of the use of light-cone superspace for the computation of off-shell quantities. The elimination of non-physical degrees of freedom in the light-front quantisation leads to potential complications associated with spurious infra-red divergences. The calculations carried out show that such infra-red divergences cancel out in gauge-invariant quantities.

1.2.4 M-theoretic AdS/CFT and Tests of the M-theory Matrix Model

(S. Kovacs with H. Shimada and Y. Sato)

Many of the most important developments in string theory over the past fifteen years originated from the understanding of a network of dualities relating the different consistent perturbative string models. A unified picture has emerged, in which these seemingly different theories arise as limits of a more fundamental eleven-dimensional theory referred to as M-theory. Little is known about this theory at present, except that it should reduce to supergravity in the low energy limit and it should contain membranes among its fundamental degrees of freedom. The best candidate for a microscopic description is the so-called matrix model of M-theory.

In the past few years there has been significant progress in our understanding of the dynamics of membranes in M-theory. This has opened up the possibility of extending the AdS/CFT correspondence to include examples relating M-theory in suitable backgrounds to supersymmetric gauge theories. A particularly interesting proposal was presented by Aharony, Bergman, Jafferis and Maldacena (ABJM), who suggested that M-theory in the $\mathrm{AdS}_4 \times S^7/Z_k$ space be dual to a certain Chern–Simons $\mathrm{U}(N)\times\mathrm{U}(N)$ gauge theory coupled to matter with $\mathcal{N} = 6$ supersymmetry.

Dr. Kovacs, in collaboration with Dr. Hidehiko Shimada (of the Institute for Quantum Physics, Okayama, Japan) and Yuki Sato (a student at Nagoya University, Japan), has developed a proposal for studying this duality in a special limit which allows to probe a genuinely M-theoretic regime. This proposal relates a class of membrane configurations in the bulk to certain gauge-invariant operators in the boundary theory. On the gravitational (M-theory) side the objects considered are classical solutions corresponding to spherical membranes carrying a large angular momentum J and their excitations. The spectrum of such states has been analysed using the matrix model regularisation. Membrane states in this sector are dual to Chern–Simons operators made of J scalar fields combined in a gauge-invariant way with so-called monopole operators. Describing these operators in the framework of radial quantisation leads to a correspondence between the spectrum of excitations of the spinning membranes and the spectrum of gauge theory states carrying a total magnetic charge J. In the limit of large angular momentum/magnetic charge, both sides of the duality are tractable using the quasi-classical approximation and therefore explicit checks of the proposal are possible. Agreement between the two sides of the duality has been verified at leading order and work is on-going to extend the analysis to higher orders.

These results provide a highly non-trivial test of the matrix model approach to M-theory in a previously inaccessible regime, which does not rely on either the low-energy supergravity approximation or compactification to type IIA string theory.

1.2.5 The Quantum Toda Chain

(I. Lyberg with T.C. Dorlas)

The (open) Quantum Toda chain is a chain of N particles with exponential interaction between nearest indices. The Hamiltonian is

$$H = -\frac{1}{2}\sum_{j=1}^{N}\frac{\partial^2}{\partial x_j^2} + \sum_{j=1}^{N-1} e^{x_j - x_{j+1}}. \qquad (1.1)$$

We consider the eigenvalue equation

$$H\psi_k = |k|^2\psi_k. \qquad (1.2)$$

Our aim is to prove the completeness relation

$$\langle\psi(x)|\psi(y)\rangle = \delta(x-y). \qquad (1.3)$$

While this has been proved by others, our proof would be simpler and more direct. Kharchev and Lebedev (2000) found a "Mellin-Barnes" representation

$$\begin{aligned}\psi_k(x) \;=\; & \int_C \prod_{n=1}^{N} \frac{\prod_{j=1}^{n}\prod_{l=1}^{n+1}\Gamma(\frac{\gamma_{n,j}-\gamma_{n+1,l}}{i})}{\prod_{1\le j,l\le n\,:\,j\ne l}\Gamma(\frac{\gamma_{n,j}-\gamma_{n,l}}{i})} \\ & \exp\Big\{i\sum_{1\le r,s\le N} x_r(\gamma_{r,s}-\gamma_{r-1,s})\Big\} \\ & \prod_{1\le p\le q\le N-1} d\gamma_{q,p}, \end{aligned} \qquad (1.4)$$

where $\gamma_{r,s} = 0$ when $s > r$, $\gamma_{N,s} = k_s$ and C is such that $\Im\gamma_{r,s} > \Im\gamma_{r+1,t}$. Our idea is to use this representation to get a series representation. For example, when $N = 2$, the normalised Mellin-Barnes representation is

$$\begin{aligned}\psi_k(x) \;=\; & \frac{1}{2\pi i\Gamma(-ik_{1,2})} \\ & \int_{a-i\infty}^{a+i\infty}\Gamma(s)\Gamma(s+ik_{1,2}) \\ & e^{-(ik_{1,2}/2+s)x_{1,2}}ds, \end{aligned} \qquad (1.5)$$

and the corresponding series representation is

$$\begin{aligned}\psi_k(x) \;=\; & \Gamma(1+ik_{1,2}) \\ & \sum_{s=0}^{\infty}\frac{e^{sx_{1,2}}}{s!}\Big(\frac{e^{ik_{1,2}x_{1,2}/2}}{\Gamma(ik_{1,2}+s+1)} \\ + \; & \frac{e^{-ik_{1,2}x_{1,2}/2}}{\Gamma(-2ik_{1,2}+s+1)}\Big). \end{aligned} \qquad (1.6)$$

We have been able to use (1.6) to prove (1.3). We hope to do the same for general N.

1.2.6 The Quantum Spherical Model

(I. Lyberg with T.C. Dorlas)

The Quantum Ising model with a transverse magnetic field is a well known model. It has the Hamiltonian

$$\mathcal{H} = -J\sum_{n=1}^{N}\sigma_n^x\sigma_{n+1}^x + B\sum_{n=1}^{N}\sigma_n^z. \qquad (1.7)$$

In the limit where the inverse temperature $\beta \to \infty$ this has a critical point at $B = J$.

The quantum spherical model is defined by the partition function

$$\begin{aligned} Z_N &= \int_{\mathsf{R}^{3N}} \delta\Big(\sum_{k=1}^{N}(x_k^2 + y_k^2 + z_k^2) - N\Big) \\ &\quad \exp \beta J \sum_{\langle j,k\rangle} z_j z_k \\ &\quad \exp \beta \sum_j (Bx_j + Hz_j)\; d^{3N}x, \quad (1.8) \end{aligned}$$

where $J > 0$, $B \geq 0$ and $H > 0$. Thus this is like the Quantum Ising model, but here each spin need not have magnitude 1. Instead, the average of the square of each spin has magnitude 1. In the limits $\beta \to \infty$ and $H \to 0$, this system has a critical point at $B = 2Jd$, where d is the dimension of the system. Specifically, the average free energy f satisfies

$$\lim_{H\to 0} \lim_{\beta\to\infty} f = -\left\{ \begin{array}{rl} Jd + B/4Jd, & B \leq 2Jd, \\ B, & B > 2Jd. \end{array} \right. \quad (1.9)$$

1.3 Independent Work by IRCSET Fellows

1.3.1 String Theory

(V. Filev)

My main research is in the area of theoretical high energy physics. More specifically, string theory and application of the AdS/CFT correspondence to the study of strongly coupled non-abelian gauge theories. I am also interested in bosonic matrix models and, in particular, near commuting multi-matrix models. During the past year, I worked on three different projects:

1.3.2 D7-brane Probes

(V. Filev)

The first project was studying backreacted D7-brane probes in the background of $AdS_5 \times S^5$ blackhole with non-vanishing B-field. This system is holographically dual to flavoured super Yang Mills theory in an external magnetic field and at finite temperature. We were interested in the thermodynamic properties of the system as well as various effects of the corresponding Yang Mills plasma in a magnetic field.

1.3.3 Magnetic Catalysis in Compact Spaces

(V. Filev)

The second project was studying the effect of magnetic catalysis in compact spaces. Our study was holographic. We considered probe D7-branes on the background of global $AdS_5 \times S^5$ space-time with constant B-field. The system is holographically dual to flavored SYM on S^3 in external magnetic field. We constructed the phase diagram of the theory and studied the meson spectrum.

1.3.4 Multi-Matrix Models

*(*V. Filev)

The third project was studying multi-matrix models in close to commuting phase. We studied a two matrix model of Yang Mills type which can be solved exactly and obtained a hemisphere distribution in its strongly coupled commuting regime. We also analyzed a related three matrix model which is also commuting at strong coupling and features uniform joint eigenvalue distribution. Finally, we analyzed three matrix models of Yang Mills type. We obtained a second loop effective action in expansion near commuting background and estimated the radius of the distribution.

1.3.5 AdS/CFT Correspondence, Gauge/Gravity Duality

(M. Ihl)

General research is in the area of AdS/CFT correspondence, gauge/gravity duality.

1.3.6 Back-reaction of Non-supersymmetric Probes

(M. Ihl with A. Kundu and S. Kundu)

Working with A. Kundu and S. Kundu, I commenced the study of unquenched flavours in the Kuperstein-Sonnenschein model at finite temperature. Namely, the backreaction of the $D7$-$\overline{D7}$-brane probes on the geometry was obtained to first order in N_f/N_c. Stability issues were addressed and the chiral symmetry breaking/restoration transition was investigated in this background, which features an interesting phase structure that is considerably richer than the one in the original model.

1.3.7 Flavoured Large N Gauge Theory on a Compact Space with an External Magnetic Field

(M. Ihl with V. Filev)

Another focus of my recent work has been the effect of magnetic catalysis in holographic models of chiral symmetry breaking. Working with V. Filev, we studied the phase structure of a flavoured $\mathcal{N} = \in$ SYM theory on a three sphere with an external magnetic field. The pairing effect of the magnetic field competes with the dissociating effect of the Casimir energy, leading to an interesting phase structure of confined and deconfined phases separated by a critical curve of a first order quantum phase transition. At vanishing magnetic field the phase transition is of a third order. For sufficiently strong magnetic field, the only stable phase is the confined phase and magnetic catalysis of chiral symmetry breaking is realized.

1.4 Independent Work by Research Scholars and Students

1.4.1 Feynman Integral

(M. Beau & T.C. Dorlas)

Working with T.C. Dorlas, M. Beau's research focuses on the Feynman formulation of quantum mechanics via the concept of path integral. The problem is that the Feynman integral, allowing the computation of the propagator of the Schrödinger equation, is not well defined. Thus, they are working on developing a rigorous mathematical formulation of the Feynman integration.

In the Lagrangian formulation of quantum mechanics one defines the *action* of a particle as an integral of the Lagrangian over the time duration of the motion:

$$S(x_f, t_f; x_i, t_i) = \int_{t_i}^{t_f} dt\, L(x(t), \dot{x}(t), t).$$

In general, the Lagrangian $L(x(t), \dot{x}(t), t)$ depends explicitly on the time, as well as on the position $x(t)$ and the velocity $\dot{x}(t)$ of the particle. For one-dimensional motion, the Lagrangian has the form

$$L(x(t), \dot{x}(t), t) = \frac{m}{2}\dot{x}(t)^2 - V(x(t), t)\ ,$$

where the first term is the kinetic energy term and $V(x(t),t)$ is the external potential. The time-evolution of a wave function $\Psi(x,t)$ is then given by

$$\Psi(x_f,t_f)=\int K(x_f,t_f;x_i,t_i)\,\Psi(x_i,t_i)dx_i, \tag{1.10}$$

where the *propagator* $K(x_f,t_f;x_i,t_i)$ is given by a *path integral* of the form

$$K(x_f,t_f;x_i,t_i)=\int e^{iS(x_f,t_f;x_i,t_i)/\hbar}\,\mathcal{D}[x(t)]. \tag{1.11}$$

Here $\mathcal{D}[x(t)]$ indicates a putative "continuous product" of Lebesgue measures $\mathcal{D}[x(t)]=\prod_{t\in(t_i,t_f)}dx(t)$. (Note that the action S above is a functional of the path $x(t)$.) It is a formidable mathematical challenge to make sense of this path-integral concept. Feynman himself interpreted it loosely as a limit of multidimensional integrals. However, as Erik G. F. Thomas (1999) remarks, even the finite-dimensional integrals are not proper integrals, though they can be defined as improper integrals. It was already noted by R. H. Cameron (1983) that the path integral cannot be interpreted as a complex-valued measure. In fact, as E. Thomas and F. Bijma show, it cannot even be interpreted as a summable distribution because the summability order diverges as the number of integrals tends to infinity. Various alternative approaches have been proposed to interpret the Feynman path integral as a limit of regularised integrals, e.g. R. H. Cameron and D. A. Storvick (1983), A. Truman (1979), E. Nelson (1964). The 'Euclidean approach' of 'Wick rotating' the time in the complex plane has led to the development of Euclidean quantum field theory, which has been the most successful way of constructing examples of quantum field theories. However, this still leaves open the question as to how the path integral object should be interpreted mathematically. De Witt-Morette (1972) has argued that it should be a kind of distribution, but her approach was formal rather than constructive. The Itô-Albeverio-Høegh Krohn (1976) approach was more constructive. They gave a definition of the path integral as a map from the space of Fourier transforms of bounded measures to itself and were able to show, using a perturbation expansion, that this is well-defined for potentials which are also Fourier transforms of bounded measures. Although the latter approach assigns a clear meaning to the path integral, it is rather restrictive in that the space of Fourier transforms of bounded measures is somewhat unwieldy and more importantly, because the space of such potentials is rather small. E. Thomas initiated a different approach, with the aim of defining the path integral as a generalised type of distribution, which he called a *path distribution.* In fact, this project is at the beginning stages. He constructed an analogue of the path integral in discrete time, where the paths are sequences in a certain nuclear sequence space. M. Beau and T. Dorlas simplify his approach by defining the path distribution on a space of paths in a Hilbert space instead. This makes the construction more explicit and the technical details less demanding. Now they try to unify the different approachs of Thomas, Itô-Albeverio-Høegh Krohn and Streit-Hida (generalized Brownian functional interpretation, 1984).

Their idea is the following: for some potential $V(x)$, they would like to define the propagator as a "dual product" between a "path distribution" and the potential test functional:

$$K_t(x_f,x_i)\equiv\langle F\ ,\ e^{-i\int_{t_i}^{t_f}d\tau\ V(x(\tau))}\rangle$$

Hence they have to solve some problems to give a proper meaning of this symbolic equation:
(1) On which space F is a distribution ? Also, what is the sense of a distribution in an

infinite dimensional space ?
(2) Then, what is the meaning of the dual product $\langle F \ , \ \cdot \rangle$
(3) The potential V belongs to a space of function, which one is suitable ?

All of these questions are a challenging program for future research, and could be interesting for Mathematical Physics as well as Mathematics.

1.4.2 Quantum Slits Experiments

(M. Beau & T.C. Dorlas)

The quantum mechanical problem of diffraction and interference of massive particles is discussed, though without detailed formulae, by R. P. Feynman in his famous lecture notes. A more exact treatment, though still lacking in detail, is in his book with A. R. Hibbs. The first experimental observation was made by Jönsson in 1961. Moreover, there are also experiments for neutron diffraction for single and double slits (Anton Zeilinger *et al*, 1988) and in quantum optics about optical interference, (see R. L. Pfleegor and L. Mandel, 1961).

M. Beau and T.C. Dorlas are interested in an analytic solution of the famous problem of diffraction and interference of electrons through one and two slits (for simplicity, only the one-dimensional case is considered). They study the approximative Feynman model (considering the motion in the propagation direction as a classical motion) to give some various approximations of the electron distribution which facilitate the interpretation of the results. The derivation is based on the Feynman path integral formula and this work could therefore also serve as an interesting pedagogical introduction to Feynman's formulation of quantum mechanics for university students dealing with the foundations of quantum mechanics.

In addition, they try to take into account the quantum-mechanical motions in all directions to solve the problem completely. This could be interesting for physicists since it could improve the accuracy of their experiments, and also because we can understand better the semiclassical limit for the propagator and prove the truncation approximation as a limit of the model for very large distances along the propagation axis compared to the size of the slit. In the Feynman model, they consider that the problem is separated into two motions, one between the source and the slits and the other one between the slits and the screen, which is not rigorously true since the time when the electron goes through the slits can not be determined (quantum mechanically). M. Beau and T.C. Dorlas are currently developing a method to compute the propagator for the diffraction in space and time problem for a localized wave packet instead of a plane wave (see M. Moshinsky 1953, J. Dalibard 1996 and A. Zeilinger 1997).

1.4.3 Stain and Stress Tensor in General Relativity Theory

(M. Beau)

M. Beau has proposed a vectorial field theory (G) based on a so-called *gravitational induction principle* where it is suggested that a density current of accelerated particles could generate a vectorial field G_μ. Starting from the construction of a Lagrangian on a Minskowski space (quadri-dimensional flat space-time):

$$L_G = -mc^2 G_\mu(x)\ddot{x}^\mu$$

(where m is the mass of the particle, $\ddot{x}^\mu$ its acceleration). Then adding the usual kinetic term, we simply obtain the dynamics equation of the mass:

$$\eta_{\mu\nu}\ddot{x}^{\nu} + \varepsilon_{\mu\nu}\ddot{x}^{\nu} + \Delta_{\mu\nu\sigma}\dot{x}^{\nu}\dot{x}^{\sigma} = 0 \qquad (1.12)$$

where the deformation tensor is $\varepsilon_{\mu\nu} \equiv \partial_\mu G_\nu + \partial_\nu G_\mu$ and the gradient of deformation tensor is: $\Delta_{\mu\nu\sigma} \equiv \partial_\nu\partial_\sigma G_\mu = \frac{1}{2}(\partial_\nu\varepsilon_{\mu\sigma} + \partial_\sigma\varepsilon_{\mu\nu} - \partial_\mu\varepsilon_{\nu\sigma})$ By the induction principle we briefly describe above, we then get the fields equations:

$$\partial_\nu\partial^\nu G_\mu(x) + \alpha\partial_\mu\partial_\nu G^\nu(x) = -\kappa\rho(x)a_\mu$$

with $a_\mu = \frac{1}{\gamma}\frac{du^\mu}{d\tau} = \frac{du^\mu}{dt}$ and $\rho(x) = \sum_\alpha m_\alpha\delta(\mathbf{x} - \mathbf{x}_\alpha(t))$ is the density of masses in the Minkowski space, where $x = (ct, \mathbf{x})$, κ is a constant.

Since in reality the masses and all kinds of energy induce a gravitational metric field, we cannot consider the Minkowskian theory as a complete theory or, furthermore, as a consistent theory. First because the space is not flat and so the vectorial field equations written above have to be covariant. Secondly because as we see in the last equations above (field and motion of particles), the acceleration of the particles due to the vectorial field should induce a vectorial field. So to be consistent we have to formulate the complete theory (with both kind of fields) in a set of dynamic equations for the fields and the impulsion-energy tensor. It was suggested the following set called the *gravitational-stress equations*:

$$\begin{cases} R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} - \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}\sigma_{\mu\nu} + \frac{8\pi G}{c^4}T_{\mu\nu} \\ D_\mu\sigma^{\mu\nu} = -\mathsf{D}_\mu T^{\mu\nu}(x) = -A^\nu(x) \\ \sigma_{\mu\nu} = C_{\mu\nu\alpha\beta}\epsilon^{\alpha\beta} \end{cases} \qquad (1.13)$$

where $T_{\mu\nu}$ is the usual impulsion-energy tensor, the tensor $\sigma_{\mu\nu}$ is called the *stress tensor* of the continuous medium, the *strain tensor* is $\epsilon_{\mu\nu} = D_\mu G_\nu + D_\nu G_\mu$ and $C_{\mu\nu\alpha\beta}$ is the *elasticity tensor* given by:

$$C_{\mu\nu\alpha\beta} = \rho_G c^2\left(g_{\mu\alpha}g_{\nu\beta} - \frac{1}{2}(1-\alpha)g_{\mu\nu}g_{\alpha\beta}\right) ,$$

where ρ_G is a constant (with the units of a density of mass) and α is a dimensionless constant. The second line of the equations (1.13) is derived by taking the covariant divergence of the first line (due to the conservation of the *total* stress-energy tensor) and so is contained in the Einstein formulation of the general relativity, except there is an additional gravitational field $G_\mu(x)$ due to the deformation of the gravitational medium. The second identity in the second line of (1.13) means that the divergence of the impulsion-energy tensor is equal to the acceleration field $A_\mu(x)$ since the matter/energy fields dynamics depend universally to the vectorial field G_μ. That means that each fields contained in $T_{\mu\nu} = T^{(1)}_{\mu\nu} + T^{(2)}_{\mu\nu} + ...$ (e.g. electromagnetic field, perfect gas..) has to verify a similar equation than (1.12) replacing the Minkowskian metric by the gravitational metric field $g_{\mu\nu}$. To compute the acceleration field $A_\mu(x) = A^{(1)}_\mu(x) + A^{(2)}_\mu(x) + ...$, we have to use the usual variational procedure the for each field applied to the modified Lagrangian density $\Lambda^{(1)\prime} = (\Lambda^{(1)} + G_\mu D_\nu T^{(1)\nu\mu})\sqrt{-g}$ coupling with the deformation vector field G_μ.

The general idea of this theory is in some way similar to the vision of the aether in the frame of the general relativity that Einstein discussed several times between 1918 and 1924, to make the acceleration and the rotation of the object compatible with the relativity theory as well as the Mach principle. The stress tensor $\sigma_{\mu\nu}$ characterizes the deformation of the medium, i.e. the so-called aether, and the theory is covariant as it was expected.

1.4.4 Matrix Models

(T. Kaltenbrunner)

I am studying the phenomenon of emergent space-time and geometry in Matrix Models. Depending on the terms in the action and the coupling parameters, the eigenvalues of the matrix/matrices behave in a random, independent manner or interact with each other. Depending on their behaviour, one can speak of space-time in the underlying space or a purely random behaviour. The phenomenon of emergent geometry is closely related to non-commutative geometry and fuzzy spaces, where the eigenvalues would form a discrete spectrum that can be classified using group theoretical concepts.

1.4.5 Edge and Tunnelling Currents

(O. Smits with Joost Slingerland)

Studies were continued on the properties of edge and tunnelling currents in fractional quantum Hall systems, for single and multiple point contacts between the edges of the system. The properties of the tunnelling currents are believed to show the presence of non-Abelian anyons at conductivity 5/2, but the experimental situation is not entirely clear. Together with Joost Slingerland, Olaf derived a fluctuation-dissipation theorem which relates the noise in the tunnelling current to the noise in the edge current.

1.4.6 Critical Phenomena

(M. Vachovski with D. O'Connor)

Numerical studies of critical phenomena in noncommutative field theories. Critical exponent measurements and numerical check of the finite size scaling laws for the case of the Three Matrix Model which is studied in detail in arXiv:0806.0558v4. Monte-Carlo study of the spectrum of near-critical fluctuations of the system using the apparatus of SU(2) coherent states and polarization tensors T_{lm}.

1.4.7 Noncommutative S^6

(M. Vachovski with D. O'Connor)

Numerical study of a matrix model which possesses fuzzy S^6 as a ground state. The model consists of 7 matrices interacting via Yang-Mills term and Chern-Simons term involving the structure constants f_{ijk} of the quaternion algebra which is related to the exceptional algebra g_2.

1.4.8 Noncommutative Scalar Model

(M. Vachovski with D. O'Connor)

Numerical study of the phase diagram and field modes in terms of polarization tensors T_{lm} of the fuzzy scalar model.

1.5 Work by Research Associates

1.5.1 The Quantum Hall Effect

(B. Dolan, Cliff Burgess, C.T. Liang & C.F. Huang)

My work on modular symmetry and the quantum Hall effect has led to a collaboration with an experimental group in Taiwan who have tested some of the predictions of modular symmetry in GaAs samples – the experimental results to date support the predictions of modular symmetry regarding the way in which the Zeeman splitting affects the temperature flow of the electrical conductivity.

Ongoing collaboration with Cliff Burgess of the Perimeter Institute, Waterloo, Canada and McMaster University, Hamilton, Ontario, Canada on duality and the modular group in the quantum Hall effect. We are currently investigating the use of AdS/CFT correspondence techniques in condensed matter systems to describe modular symmetries in the quantum Hall effect and other strongly correlated electron systems.

1.5.2 Non-commutative Geometry

(B. Dolan, D. O'Connor & Richard Szabo)

Ongoing programme to develop closed matrix algebras approximating compact manifolds, one aim of which is numerical computation.

Collaboration with Richard Szabo of Heriot-Watt University on equivariant dimensional reduction, using fuzzy spaces as internal spaces.

1.5.3 General Relativity

(B. Dolan, R. Mann, D, Kubiznak. D. Kastor & J. Traschen)

Enthalpy and pressure in black hole thermodynamics. We are investigating the role of the cosmological constant in providing a pressure term in the First Law of black-hole thermodynamics.

1.5.4 Higher Dimensional Field Theories

D.H. Tchrakian

Research in the area of higher dimensional field theories, including dimensional descent. Abelian and non Abelian gauged Higgs and Skyrme field theories, including their gravitating cases. Special emphasis on higher curvature Yang–Mills and gravitational terms, as well as Chern-Simons terms. Inclusion of (negative) cosmological constant in gravitating systems with flat horizon (planar geometry). Hopfions in higher dimensions. Specific problems tackled are listed below.

- The construction of electrically charged black-branes in $4+1$ dimensional supergravity theory, in planar geometry. This is achieved by positing a consistent Ansatz for the $k=0$ Yang-Mills field with suitable large gauge freedom. Our final aim is to carry this out for $\mathcal{N}=8$ supergravity which includes the scalar (dilatonic) sector.

- The construction of dyons of Yang-Mills–Chern-Simons in $2n+1$ dimensional spacetime, for $n \geq 3$, *i.e.* for $d = 7, 9, \ldots$. We have described these as *instantonic dyons* to distinguish them from the *dyonic instantons* of Lambert and Tong, which we have shown exist only in $d=5$. The latter feature a quadratic Higgs like term in contrast to the Chern-Simons terms in our models.

- The study of gravitating non-Abelian systems whose (finite energy) solutions are stable versus the corresponding Reissner-Nordström solutions. These systems feature the electric component of the non-Abelian connection, achieved by suitably enlarging the gauge group that had served the purely magnetic case. This was carried out in $3+1$ dimensions, and is now extended to $4+1$ and higher dimensions.

- New Chern-Simons(–Higgs) terms in both **even** and **odd** spacetime dimensions. These are constructed from the corresponding Chern-Pontryagin densities arrived at via dimensional descent of Chern-Pontryagin densities of Yang-Mills systems in higher **even** dimensions.

- Constructing Abelian and non-Abelian Hopfions in $2n+1$ dimensions. Abelian systems considered are the CP^n sigma models, while the non-Abelian systems are Grassmannian like models with gauge-freedom $SO(2n) \times SO(2)$.

2 PUBLICATION OF RESEARCH RESULTS

2.1 Papers in Refereed Journals

[1] B. Dolan, Y-T. Wang, G-H. Kim, C.F. Huang, S-T. Lo, W-J. Chen, J.T. Nicholls, L-H. Lin, D.A. Ritchie, Y-H. Chang and C.T. Liang. "Probing temperature-driven flows lines by varying effective spin-splitting in a two dimensional electron gas containing self-assembled InAs dots," *J. Phys: Condensed Matter* **24** (2012) 405801.

[2] B. Dolan, J. Medina, Y. Huet and D. O'Connor. "Scalar and Spinor Field Actions on Fuzzy S^4: fuzzy CP^3 as a S^2_F bundle over S^4_F," *JHEP* **08** (2012) 070.

[3] A. Ballon-Bayona, H. Boschi-Filho, N. R. F. Braga, M. Ihl and M. A. C. Torres, "Production of negative parity baryons in the holographic Sakai-Sugimoto model," *Phys. Rev. D* **86**, 126002 (2012).

[4] M. Ihl, A. Kundu and S. Kundu, "Back-reaction of Non-supersymmetric Probes: Phase Transition and Stability," *JHEP* **1212**, 070 (2012).

[5] H. Boschi-Filho, N. R. F. Braga, M. Ihl and M. A. C. Torres, "Relativistic baryons in the Skyrme model revisited," *Phys. Rev. D* **85**, 085013 (2012).

[6] Yves Brihaye, Eugen Radu and D.H. Tchrakian, "An instability of the Reissner-Nordström solution and new hairy black holes in d=5 dimensions," *Phys. Rev. D* **85** (2012) 044041.

[7] Yves Brihaye, Eugen Radu and D.H. Tchrakian, "Stable black hole solutions with non-Abelian fields," *Phys. Rev. D* **85** (2012) 084022.

[8] Eugen Radu and D.H. Tchrakian, "Instantonic dyons of Yang-Mills–Chern-Simons models in d=2n+1 dimensions, n>2," *J. Phys. A* **45** (2012) 345401.

[9] M. Beau, "Feynman Path Integral approach to electron diffraction for one and two slits, analytical results," *Eur. J. Phys.* **33**, 1023 (2012).

[10] M. Ammon, V. G. Filev, J. Tarrio and D. Zoakos, "D3/D7 quark-gluon plasma with magnetically induced anisotropy," *JHEP* **1209**, 039 (2012).

[11] J. Erdmenger, V. G. Filev and D. Zoakos, "Magnetic catalysis with massive dynamical flavours," *JHEP* **1208**, 004 (2012).

[12] S. Ananth, S. Kovacs and S. Parikh, "Gauge-invariant correlation functions in light-cone superspace," *JHEP* **1205**, 096 (2012).

[13] V. Braun, "The 24-Cell and Calabi-Yau Threefolds with Hodge Numbers (1,1)," *JHEP* **05**, 101 (2012).

[14] V. Braun, P. Candelas, R. Davies, R. Donagi, "The MSSM Spectrum from (0,2)-Deformations of the Heterotic Standard Embedding," *JHEP* **05**, 127 (2012).

[15] F. Hofmann, B. Abbey, L. Connor, N. Baimpas, X. Song, S. Keegan, A.M. Korsunsky, "Imaging of grain level orientation and strain in thicker metallic polycrystals by high energy transmission micro-beam Laue (HETL) diffraction techniques," *Int. J. Mat. Res.* **103** (2012).

[16] Lara B. Anderson, Volker Braun, Robert L. Karp and Burt A Ovrut:

Numerical Hermitian Yang-Mills Connections and Kahler Cone Substructure, *JHEP* **01**, 014 (2012).

[17] Rodrigo Delgadillo-Blando, Denjoe O'Connor: Matrix geometries and Matrix Models, *JHEP* **11**, 057 (2012).

[18] Werner Nahm: The placement and chronological sequence of the stelae from Assur, *Altorientalische Forschungen* **39, 1**, pp. 112-123.

2.2 Papers in Conference Proceedings

[1] H. Boschi-Filho, N. R. F. Braga, M. Ihl and M. A. C. Torres, "Towards Relativistic Skyrmions," *PoS ICMP* **2012**, 020 (2012).

[2] E. Radu, D.H. Tchrakian, "New Chern-Simons densities in both odd and even dimensions," to appear in *Low Dimensional Physics and Gauge Principle, Matinyan Festschrift*, World Scientific (Singapore), edited by V.G. Gurzadyan, A. Klümper and A.G. Sedrakyan.

[3] V. Braun, "Counting Points and Hilbert Series in String Theory," in *Max Kreuzer memorial volume*

2.3 Preprints

DIAS-STP-

[12-01] Beau, M., Dorlas, T. C.: Discrete-Time Path Distributions on Hilbert Space.

[12-02] Balasubramanian, V., Berglund, P., Braun, V., Garcia-Etxebarria, I.: Global embeddings for branes at toric singularities.

[12-03] Kovacs, S., Ananth, S., Parikh, S.: Gauge-invariant correlation functions in light-cone superspace.

[12-04] Filev, V.: D3/D7 Quark-gluon plasma with magnetically induced anisotropy.

[12-05] Dolan, B., Szabo, R.: Solitons and Yukawa couplings in nearly Kahler flux compactifications.

[12-06] Ihl, M.: Back reaction of non-supersymmetric probes.

[12-07] Dolan, B.: Where is the PdV term in the first law of black hole thermodynamics.

[12-08] Beau, M.: Hypothèse théorique concernant l'induction d'un champ gravitationnel de type vectoriel généré par le déplacement accéléré des masses en mouvement.

[12-09] Ihl, M.: Production of negative parity baryons in the holographic Sakai-Sugimoto model.

[12-10] Ihl, M., Filev, V.: Flavoured large N-gauge theory on a compact space with an external magnetic field.

[12-11] Brihaye, Y., R. Manvelyan, E. Radu, and D.H. Tchrakian: Electrically charged black branes in N=4^+, D=5 gauged supergravity.

[12-12] O'Connor, D., Filev V.: Near commuting multi-matrix models.

[12-13] Braun, V.: Counting points and Hilbert series in string theory.

[12-14] Medina, J., Huet, I., O'Connor, D., Dolan, B. P.: Scalar and spinor field

actions on fuzzy S^4: fuzzy CP^3 as a S^2_F bundle over S^4_F.

[12-15] Delgadillo-Blando, R., O'Connor, D.: Matrix geometries and matrix models.

[12-16] Boschi-Filho, H., Braga, N.R.F., Ihl, M., Torres, M.A.C.: Towards relativistic Skyrmions.

[12-17] Lyberg, I.: A "Quantum spherical model" with transverse magnetic field.

[12-18] Nahm, W.: Generation by sections and k-Ampleness.

[12-19] Nahm, W.: A general vanishing theorem.

2.4 Miscellaneous

[1] Dorlas, T.C. Contribution to 'In Memoriam' for Professor Erik G.F. Thomas in the *Nieuw Archief voor Wiskunde* **5/13**, no. 4, Dec. 2012.

[2] Dolan, B. "Where is the PdV term in the first law of black hole thermodynamics?" *Open Questions in Cosmology*, ed. G.J. Olmo (2012) InTech, ISBN 978-953-51-0880-1, (arXiv:1209.1272)

3 Programme of Scholarly Events

3.1 Lectures Organised by The School

- "Non-Abelian and Fermionic T-Duality" by Eoin O Colgain, School of Mathematics, TCD, 4 January.
- "Fermi Systems with Long Range Interactions" by Dr. Jean-Bernard Bru, Dept. of Mathematics, UPV-EHU (Leioa, Spain), 24 April.
- "Fractional Quantum Hall Effect of Lattice Bosons Near Commensurate Flux" by Layla Hormozi, NUI Maynooth, 4 October.
- "Thermodynamics and Transport Coefficients from QCD Correlation Functions" by Jan Pawlowski, Institute für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, 6 December.

3.2 Symposia, Conferences, Workshops Organised

- A conference on *Quantum Physics and Bethe Ansatz*, held at DIAS, 8-10 October 2012. Organised by T.C. Dorlas and M. Beau.
- A workshop on *Holography and Magnetic Catalysis of Chiral Symmetry Breaking*, held at DIAS, 19-22 November, funded by the HoloGrav Network. Organised by D. O'Connor and V. Filev.

3.3 Statutory Public Lecture

The 2012 Statutory Public Lecture was held in association with the School of Cosmic Physics and was delivered by Professor Martin Rees, Baron Rees of Ludlow, O.M., F.R.S., on the 19th of November at UCD. The title was: *Cosmic perspectives: from planets to the multiverse.*

4 PRESENTATION OF RESEARCH WORK AT CONFERENCES/SEMINARS

4.1 National

T.C. Dorlas

- Talk: "Quantum Error-Correcting Codes: Examples and Bounds on the Capacity" at the conference on *Algebra, Combinatorics, Dynamics and Applications* at Queen's University, Belfast, 30 August.

M. Beau

- Talk: "The time-interference of the electron for the slit experiment," at *Quantum Physics and Bethe Ansatz* conference, DIAS, 8-10 October.

Brian Dolan

- Talk: "Holography and Magnetic Catalysis of Chiral Symmetry Breaking," at DIAS, 19-22 November.

M. Ihl

- Talk: "Introduction to gauge/gravity correspondence and applications to (holographic) QCD," at DIAS, 10 November.
- Talk: "Backreacted flavours in the Kuperstein-Sonnenschein model" at the Dublin Theoretical Physics Colloquium, Trinity College, 12 November.
- Talk: "Magnetic Catalysis in the (backreacted) Kuperstein-Sonnenschein model" at the *Holography and Magnetic Catalysis of Chiral Symmetry Breaking* workshop, DIAS, 21 November.

I. Lyberg

- Talk: "The Weyl Group", at DIAS, Spring.
- Talk: "The Quantum Toda chain,"at the *Quantum Physics and Bethe Ansatz* conference, DIAS, 8-10 October.

T. Kaltenbrunner

- Talk: "Superspace and Superfields," DIAS Seminar, DIAS, 12 May.
- Talk: "B-Meson Decay at LHC," DIAS Seminar, DIAS, 19 May.
- Talk: "Eigenvalue distributions of Yang Mills matrix models" at the DIAS Board Meeting, DIAS, 18 November.

S. Kovacs

- Talk: "Membranes in the AdS_4/CFT_3 correspondence," at the *Workshop on Holography and Magnetic Catalysis of Chiral Symmetry Breaking*, DIAS, 20 November.

4.2 International

W. Nahm

- Talk: "The embedding of quantum field theory in mathematics" at the *Mathematical Foundations of Quantum Field Theory Workshop*, Simons Center for Geometry, Stonybrook, NY, 18 January.
- Talk: "The discrete Hirota equation, the Ising model, and CFT" at the *3rd O'Raifeartaigh Conference on Symmetry and Integrability,* Arnold Sommerfeld Center for Theoretical Physics, Munich, 20 July.

T.C. Dorlas

- Talk: "Discrete-time Feynman path integral as a path distribution" at the Joint Institute for Nuclear Research, Dubna, Russia, 29 February.

- Talk: "Discrete-time Feynman path integral as a path distribution" at Chalmers University, Gothenburg, Sweden, 13 June.

- Talk: "Discrete-time Feynman path integral as a path distribution" at the conference on *Algebra, Geometry and Mathematical Physics* in Tallinn, Estonia, 10-14 July.

D. O'Connor

- Talk: "Multi-Matrix Models "at the conference *INI-WIMCS meeting on Noncommutative Geometry* at Cardiff University, 17 April.

M. Beau

- Talk: "Path distribution on Hilbert space," at *International Conference of Mathematical Physics Young Researcher Symposium*, Aalborg, Denmark, 3-4 August.

V. Braun

- Talk: "Geometry of the compact directions: a numerical approach to Sasaki-Einstein and Calabi-Yau metrics," at the KITP program *Novel Numerical Methods for Strongly Coupled Quantum Field Theory and Quantum Gravity*, UCSB, Santa Barbara, CA, 2 March.

- Talk: "Toric Elliptic Fibrations and F-Theory," at the conference on *String Theory for Mathematicians*, Simons Center for Geometry and Physics, Stony Brook, NY, 13-18 May.

- Seminar talk: "F-Theory and Toric Elliptic Fibrations," at Imperial College, London, 29-31 May.

- Talk: "Toric Elliptic Fibrations and F-Theory," at Universita degli Studi di Milano, Italy, 31 May-5 June.

- Talk: "Global F-theory models," at the conference *New Challenges for String Phenomenology*, at IFT-UAM/CSIC Madrid, Spain, 25-29 September.

V. Filev

- Talk: "Unquenched holographic magnetic catalysis," at the University of Santiago de Compostela, October.

- Talk: "Unquenched holographic magnetic catalysis," at the University of Porto, October.

M. Ihl

- Talk: "Mesons and baryons in holographic models of QCD (and related models)," at Kavli IPMU, Tokyo, Japan (also at KIAS, Seoul, Korea), 24 May.

- Talk: "Backreaction of flavours in the Kuperstein-Sonnenschein model," at Swansea Theory Group Seminars, Swansea, UK, 30 November.

D. H. Tchrakian

- Talk with E. Radu on: "Abelian and non-Abelian Hopfions in all odd dimensions, at quantized flux in tightly knotted and linked systems," at the Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, 3-7 December.

5 COLLABORATION WITH WIDER RESEARCH COMMUNITY

5.1 National

5.1.1 Lecture Courses and Workshops

T. Dorlas

- Taught 10 week course on Mathematical Calculus to higher level leaving certificate students, October-December.

S. Kovacs

- Taught courses on Classical Mechanics I & II (MA1241 & MA1242) for Junior Freshman Mathematics and Theoretical Physics students, Trinity College Dublin, Academic Years 2011-12 and 2012-13.

5.1.2 Research Collaboration

D.H. Tchrakian

- Collaboration with: Prof Jürgen Burzlaff (DIAS and DCU) on: Properties of *almost selfdual Skyrmions*.

5.1.3 Staff Acting as External Supervisors

- Denjoe O'Connor: Ph.D. supervisor for Thomas Kaltenbrunner (Maynooth) partly funded by the EU-NCG network.
- Denjoe O'Connor: Ph.D. supervisor for Martin Vachovski (Maynooth) partly funded by the EU-NCG network.

5.1.4 Research Associates

- AT&T: N. Duffield
- BM Annaba University: B. Ydri
- DCU: E. Buffet, J. Burzlaff, E. O'Riordan
- DIT: D. Gilbert, M. Golden, B. Goldsmith, P. Houston, E. Prodanov
- ICTP, Trieste: J. Chela-Flores
- IT, Athlone: M. Daly
- IT, Carlow, D. O Sé
- IT, Tallaght: N. Gorman
- Ludwig-Maximillians-Universität München: I. Sachs
- Meteorological Service: P. Lynch
- NUI, Cork: M. Vandyck
- NUI, Galway: J. Burns, M.P. Tuite
- NUI, Maynooth: B. Dolan, D. Heffernan, C. Nah, A. O'Farrell, J. Slingerland, J. Vala, P. Watts
- Open University: A.I. Solomon
- Oxford University: R.G. Flood
- TCD: P.S. Florides, J. Miller, D. Weaire
- Universiteit Leiden: F. Freire
- UCD: A. Ottewill, J.V. Pulé, W. Sullivan
- UL: S. O'Brien
- University Warwick: N. O'Connell
- Unaffiliated: T. Garavaglia, M. Leitner, G.M. O'Brien, D. O'Mathuna, J.A. Slevin, D.H. Tchrakian
- Waterford Institute of Technology: Cormac O'Raifeartaigh

5.2 International

5.2.1 Visiting Researchers

Short visits (up to one week):

- Harald Seibel, German Embassy, Dublin, 8 March.
- Jean-Bernard Bru, University of the Basque Country, 23-26 April.
- Xavier Martin, Departement de Physique, Universite Francois Rabelais-Tours, May.
- Valentin Zagrebnov, Université d'Aix Marseille, 8-9 October.
- Eric Eriksson, University of Gothenburg, 8-11 October.
- Neil O'Connell, University of Warwick, 8-10 October.
- Daniel An, SUNY Maritime College, 8-11 October.
- Baptiste Savoie, University of Aarhus, Denmark, 8-11 October.
- Jean-Bernard Bru, University of the Basque Country, 7-11 October.
- Natalia Iyudu, Queen's University, Belfast, 8-11 October.
- Sonia Mazzucchi, CIRM, University of Trento, Italia, 8-11 October.
- Ciara Morgan, CQT, Singapore, 8-11 October.
- Alexander Stolin, Göteberg, Sweden, 8-11 October.
- Horia Cornean, Aalborg, Denmark, 8-11 October.
- Simon Ruijsenaars, Leeds, UK, 8-11 October.
- Aleksey Kostenko, Vienna, Austria, 6-15 October.
- Martin Rees, University of Cambridge, UK, 18-19 November.
- Andreas Schmitt, Vienna, Austria, 19-22 November.
- Tigran Kalaydzhyan, Hamburg, Germany, 18-22 November.
- Matthew Lippert, University of Amsterdam, 18-22 November.
- Dimitrios Zoakos, Porto, Portugal, 18-22 November.

Long visits:

- Tom Spencer, Institute for Advanced Study, Princeton, 30 April-20 May.
- V. B. Priezzhev, Joint Institute for Nuclear Research, Dubna, Russia, 1-20 October.
- A. Povolotsky, Joint Institute for Nuclear Research, Dubna, Russia, 1-20 October.
- Ruben Manvelyan, Yerevan Physics Institute, Armenia, 10 April-1 May.
- E. Radu, Oldenburg, April.
- Yves Brihaye, Mons, April.

5.2.2 Research Visits by School Staff

T.C. Dorlas

- Visit to the Joint Institute for Nuclear Research, Dubna, Russia, 24 Feb. - 7 March.
- Visit to Chalmers University, Göteborg, Sweden, 10-15 June.
- Visits to Cambridge University, 2-6 and 25-28 September and 20-23 November.

V. Braun

- Visit to University of Pennsylvania, PA, USA, 10 July-4 August.
- Visit to University of Pennsylvania, PA, USA, 1-18 November.

B. Dolan

- Visit to Heriot-Watt University, Edinburgh, 12 January.

V. Filev

- Visiting scholar at Sofia University, July-August.
- Visiting scholar at University of Santiago de Compostela, October.
- Visiting scholar at University of Porto, October.

M. Ihl

- Research visit to University of Texas at Austin, USA, March.
- Research visit to Kavli IPMU, Tokyo, Japan, May.

D.H. Tchrakian

- Research visit to Max-Planck-Institut, Munich, for collaboration with Peter Breitenlohner, July.
- Research visit to Mons, for collaboration with Yves Brihaye, November.
- Research visit to Kairerslautern, for collaboration with Ruben Manvelyan, November.

6 PARTICIPATION IN OUTSIDE COMMITTEES

D. O'Connor

- Member of International Advisory Board of the Central European Joint Programme of Doctoral studies in Theoretical Physics.
- External advisor to the Graduate Program in Theoretical Physics, Annaba University Algeria.

B. Dolan

- Acted as referee for 6 articles in the journals: JHEP, PRD, JPA, European Physics Journal Plus, Canadian Journal of Physics, Scientific Reports.
- International expert on physics review panel for Romanian National Research Council: Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI).
- Editor for Physics section of Nature: Scientific Reports.

7 Attendance at External Conferences, Workshops, Scientific Meetings, and Lectures At Home and Abroad

7.1 Conferences/Workshops/ Scientific Meetings Attended

Denjoe O'Connor

- Aspects of Conformal and Superconformal Field Theories, A Commemoration of the Work of Francis Dolan, University of Cambridge, 12-14 April.

- INI-WIMCS meeting on Noncommutative Geometry, Cardiff University, 16-20 April.
- 3rd O'Raifeartaigh Conference on Symmetry and Integrability, Ludwig Maximilian University of Munich, 19-21 July.

M. Beau

- International Conference of Mathematical Physics, Aalborg (Denmark), 6-11 August.

V. Braun

- Workshop Sage Days 35.5, Gordon College, Wenham, MA, USA, 8-11 January.
- KITP program "Novel Numerical Methods for Strongly Coupled Quantum Field Theory and Quantum Gravity "at UCSB, Santa Barbara, CA, USA, 17 January-9 March.
- Workshop "P-Adics in Sage "at UCSD, San Diego, CA, USA, 19-22 February.
- Workshop of the "String Vacuum Project "at University of Pennsylvania, Philadelphia, PA, USA, 16-18 March.
- Conference on "String Phenomenology "at Simons Center for Geometry and Physics, Stony Brook, NY, USA, 22-27 April.
- Conference on "String Theory for Mathematicians "at Simons Center for Geometry and Physics, Stony Brook, NY, USA, 13-18 May.
- "Sage Days 38, "Seattle, WA, USA, 24-28 May.
- Conference at Universita degli Studi di Milano, Italy.
- Simons Workshop, Simons Center for Geometry and Physics, Stony Brook, NY, USA, 5-17 August.
- "Singular/GAP Workshop, "St. Andrews, UK, 26-31 August.

B. Dolan

- 33rd North British Mathematical Physics Seminar, Appleton Tower, University of Edinburgh, Edinburgh. 21 March.
- 3rd O'Raifeartaigh Conference on Symmetry and Integrability, Ludwig Maximilian University of Munich, 19-21 July.
- "Dark matter, dark energy, black holes and quantum aspects of the Universe, "at 9th Vienna Central European Seminar on Particle Physics and Quantum Field Theory, 30 November-2 December.

V. Filev

- "Gravity Theories and their Avatars, "at Crete Center of Theoretical Physics, Heraklion, 13-19 July.
- Workshop on *Holography and magnetic catalysis of chiral symmetry breaking* , at DIAS, 18-22 November.

T. Kaltenbrunner

- Workshop on *Holography and magnetic catalysis of chiral symmetry breaking*, DIAS, 19 November.

S. Kovacs

- Workshop on *Holography and magnetic catalysis of chiral symmetry breaking*, at DIAS, 18-21 November.

I. Lyberg

- "3Quantum: Algebra, Geometry, Information "conference, organised by AGMP network, Tallinn University of Technology, Tallinn, Estonia, 10-13 July.
- Summer school on Quantum Ergodicity and Harmonic Analysis, University of Marburg, 3-5 September.

D.H. Tchrakian

- "3rd O'Raifeartaigh Conference on Symmetry and Integrability ", Ludwig Maximilian Universität, Munich, 19-21 July.
- "Quantized Flux in Tightly Knotted and Linked Systems ", Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, 2-7 December.

7.2 Lectures and Organisational Meetings Attended

I. Lyberg

- Irish Mathematical Society meetings, Tallaght, 27 and 28 August.

8 RESEARCH GRANTS/EXTERNAL FUNDS SECURED

D. O'Connor

- 2011-2013: An Embark Initiative Postdoctoral Fellowship to Mathias Ihl funded by IRCSET for a period of two years years with effect from 1 September 2011.
- 2010-2013: An INSPIRE Initiative Postdoctoral Fellowship to Veselin Filev funded by IRCSET and Marie Curie.

V. Filev

- Holograv ESF funding for small workshop, November.
- IRCSET/Marie Curie, INSPIRE Postdoctoral Research Fellowship, August 2010-July 2013.

9 HONOURS/AWARDS/ SPECIAL ACHIEVEMENTS RECEIVED

W. Nahm

- Awarded 2012 Gothenburg Lise Meitner prize by the Chalmers University of Technology and The University of Gothenburg.

D. O'Connor

- Admitted as a new member of the Royal Irish Academy, 25 May.

10 PUBLIC AWARENESS INITIATIVES AND ACTIVITIES UNDERTAKEN

Brian Dolan

Talk "This Blinding Absence of Light: Black holes, dark matter and dark energy" at Maynooth Skeptics Society, 17 October.